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A Survey Assessment of Soviet Electro-Optics Technology and Applications (Annexes A Through C)

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Scientific and Technical Intelligence Committee

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STIC 85-006
December 1985

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Note to Readers

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Preface

The Scientific and Technical Intelligence Committee's (STIC's) Electro-Optics Working Group (EOWG) convenes regularly to review developments and clarify differences within the US Intelligence Community relating to electro-optics (EO) technology, research, development, and applications. Electro-optics is an emerging technology, and new developments are occurring frequently. The potential for many of the applications is not yet well defined. This report assesses the present state of the art of EO technology within the Soviet Union, discusses some possible military applications, and estimates the impact this technology might have upon military systems. For this study, we have considered electromagnetic frequency spectrum sources from 0.01 to 1000 micrometer (μm) wavelength as falling in the category of electro-optics. [redacted] 25X1

Questions concerning the content of this report should be directed to the Chairman of the Electro-Optics Working Group, Mr. Denver Stone, [redacted] Members and alternate members of the EOWG who drafted this report are: 25X1

Mr. Denver Stone (*Chairman*)	Department of the Army/FSTC
Mr. J. M. Finley (*Cochairman*)	Department of the Air Force/FTD
Mr. Arthur G. Cobleigh, Jr.	Department of the Navy/NISC
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Dr. George F. Riley	Department of the Army/FSTC
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	National Security Agency
Ms. Patricia Tarry	Department of the Navy/NISC
[redacted]	National Security Agency 25X1

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Contents

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List of Abbreviations and Acronyms

AC	alternating current or voltage
AOM	acousto-optic modulator
$BaTiO_3$	barium titanate
BMD	ballistic missile defense
CdS	cadmium sulfide, detector material
CCD	charge coupled device
CRT	cathode ray tube, picture tube
CO_2	carbon dioxide
C^3I	command, control, communications, and intelligence
CW	continuous wave, continuous operation
COM	coherent optical modulator
*D**	D-star, value of specific detectivity of an optical detector, expressed in cm $Hz^{-1/2}$ per W
dB	decibel
DC	direct current or voltage
ED	electronic-digital processing or computing
EIR	extreme infrared
ELINT	electronic intelligence
EMP	electromagnetic pulse
E-O	electro-optics
EOWG	Electro-Optics Working Group of STIC
EUV	extreme ultraviolet
EW	electronic warfare
FIAN	Physics Institute *imeni* P. N. Lebedev, Moscow
FLIR	forward-looking infrared (applied to many infrared viewers)
FOCL	fiber-optic communications line
FTI	Physico-Technical Institute *imeni* A. F. Ioffe, Leningrad
GaAs	gallium arsenide, semiconductor material
GaAlAs	gallium aluminum arsenide
Ge:Au	gold doped germanium
GHz	gigahertz, 10^9 Hz
HgCdTe	mercury cadmium telluride, detector material
Hz	hertz, cycles per second
IFOV	instantaneous field of view
InSb	indium antimonide, detector material
IR	infrared
IRE	Institute of Radio Engineering and Electronics, Moscow
KGB	Soviet Committee of State Security
LCLV	liquid crystal light valve
LFM	linear frequency modulation
LIDAR	light radar, laser radar
$LiNbO_3$	lithium niobate
LPE	liquid phase epitaxy
LPI	Leningrad Polytechnic Institute *imeni* M. I. Kalinin
MIFI	Moscow Engineering-Physics Institute
MRΔT	minimum resolvable temperature difference
NATO	North Atlantic Treaty Organization
Nd:YAG	neodymium doped yttrium aluminum garnet, laser material
nm	nanometer, 10^{-9} m
OP	optical processing or processor
PbS	lead sulfide, detector material
PbSe	lead selenide, detector material
PRN	pseudorandom noise
PRIZ	acronym from Russian for image transformer
PROM	Pockels (effect) read-out optical modulator
rad	radian, angular measure, approximately 57.3 degrees
rad	measure of radiation dose absorbed
RF	radiofrequency
SACLOS	semiautomatic command to line of sight, missile guidance scheme
SAL	semiactive laser
SAR	synthetic aperture radar
SAW	surface acoustic wave, device, or effect
Si	silicon
SLM	spatial light modulator
SPIE	Society of Photoptical Instrumentation Engineers
STIC	Scientific and Technical Intelligence Committee of the Director of Central Intelligence
TB	time-bandwidth product
TGS	triglycerine sulfide, detector material
TV	television
μm	micrometer, 10^{-6} m
UV	ultraviolet

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Annex A

Technical Considerations

Introduction

The Soviet effort devoted to the development of electro-optics (EO) technology is probably much greater than that of the United States. The exact magnitude of the Soviets' effort—measured in rubles, number of technical personnel, and facility floorspace is not known. Reports of their EO activities, organizational changes, political and military support, and scientific achievements, however, suggest that they are using EO technology in some specific areas to compensate for deficiencies in their electronic digital technology. [redacted]

During the early 1970s the Politburo established a policy ordering that "optoelectronic technology be developed for real-time applications in military systems." Subsequently, four commissions were formed to plan, direct, and manage EO developments to meet this policy. The chairmen of these commissions are highly competent scientists and managers. Some have achieved international recognition for their accomplishments. Dr. L. D. Bakhrakh, for example, has earned two Lenin prizes for work in EO related to synthetic aperture radar developments. [redacted]

The Soviets have placed a high priority in recent years on the development and deployment of large conventional forces—sea, land, and air. "Smart" weapons, offering high reliability and accuracy, are playing a strong role in strengthening these forces. Senior Soviet military officials have often stated their concepts and expectations for such weapon systems. They believe that the use of the emerging high technology, with high accuracy and reliability, is essential for operational success. The Soviets have performed an analysis of US operations in Southeast Asia and have published the "lessons learned" for the benefit of their weapon systems designers, strategists, and tacticians. Their analysis suggests that operational missions (sorties) may be reduced by 2 to 3 orders of magnitude and resources expended reduced by 1 to 2 orders of magnitude for each target destroyed if "smart" weapons are used instead of conventional weapons and techniques. They believe these statistics developed over the past two decades emphasize the need for development of "electro-optics technology for real-time application to weapon systems." [redacted] 25X1

Technologies

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Optical Processing

Advanced radar designs, sonar, reconnaissance systems, missile guidance, electronic warfare, and advanced communications systems require increased processing capacity to keep abreast of the computation load produced by the larger bandwidth and longer time-bandwidth products of new sophisticated waveforms, pulse code formats, as well as the richer target and denser signal environments anticipated during the next decade. Optical processors are attractive for these applications because they have large bandwidths and larger time-bandwidth products and other characteristics—such as substantial (often several orders of magnitude) reductions in size, weight, power, and cost, as well as increases in overall system reliability. 25X1 Optical processors are attractive for many applications because of their high data capacity, high throughput rates, and their ability to perform real-time parallel processing. Optical processing systems may be separated into two classes: image processors and signal processors. Image processors usually provide two-dimensional specific data on the image or a decision on the input image. The identification and location of a specific object in the image may be determined. Signal processors, on the other hand, process one-dimensional data, and their outputs are usually one-dimensional quantities—such as range, velocity, acceleration, and angle to the target. In addition, signal processors, such as those used for synthetic aperture radar, can also be designed to synthesize an image at the output. A generic model of an optical processor is shown in figure A-1. [redacted] 25X1

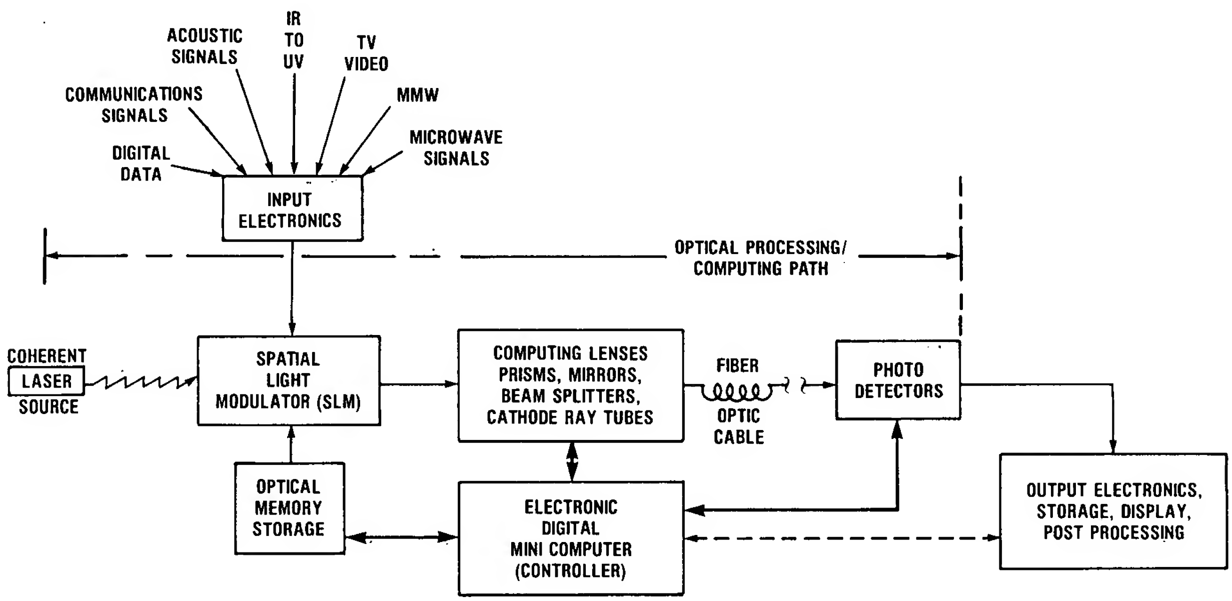

Figure A-1. Electro-Optic Processing/Computing Path (Generic Model)

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Some of the common input signals for optical processors are raw, unprocessed electromagnetic phenomena in various formats and modes. Processing algorithms and mathematical manipulations must be applied to the data to extract useful (processed) information suitable for decisionmaking or further postprocessing, data fusion, or additional manipulation. The conventional (nonoptical) means for accomplishing this function uses electronic digital or analog technology. As suggested by figure A-1, a mathematical transformation from the input temporal domain to the spatial domain occurs at the input device, the spatial light modulator (SLM). In essence, the input signal is transferred to a light source, SLM, lens, mirrors, prisms, electronic controllers, fiber-optic light guides (cables), and photodetectors. The photodetectors permit the reverse transformation back to the temporal domain for final display, storage, or decisionmaking.

The illustration in figure A-2 provides a simplified description of the capability of a spherical lens to perform a complex, two-dimensional mathematical integration (Fourier transformation) of a function, g(x,y), illustrated in the front focal plane (input plane). The spatial Fourier transform, G(u,v), is displayed in the back focal plane (output plane). Variations of this mathematical computation could include cylindrical or conical lens cuts dimensioned for specific computational needs. Thus the primary motivational factors for an optical processor—parallel operation, high data capacity, very high throughput rates—are illustrated. The high frequency of a visible-light laser (nominally 600,000 GHz), as compared with a modern, sophisticated airborne intercept radar (nominally 10 GHz)

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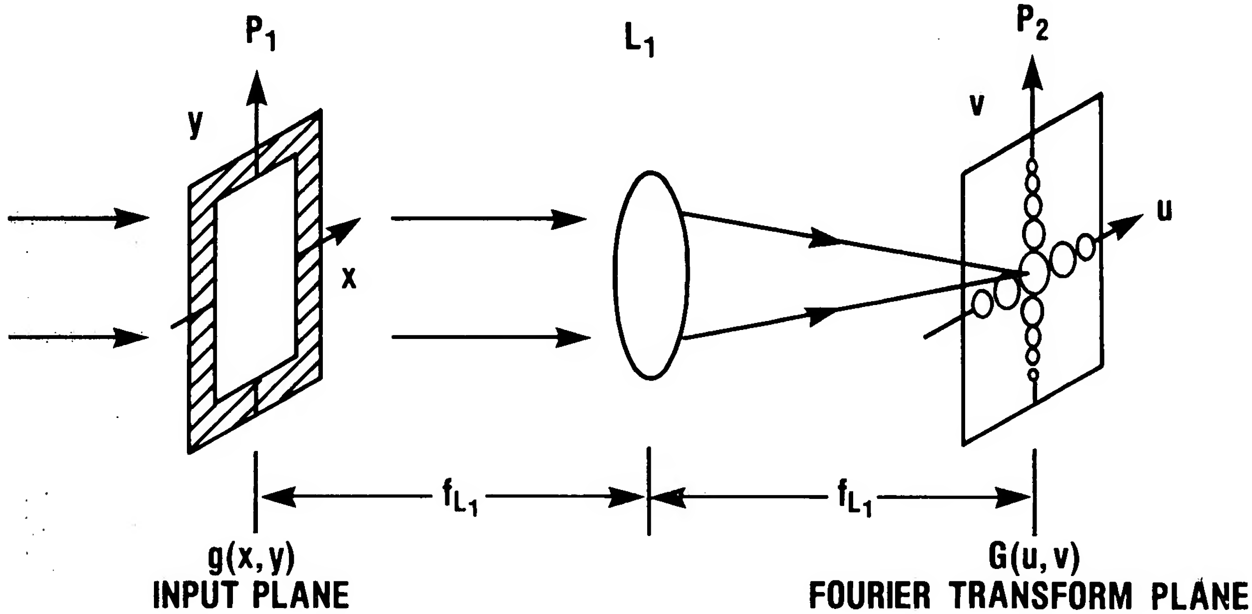

OUTPUT AT FOURIER TRANSFORM PLANE:

$$G(u,v) = \iint_{-\infty}^{+\infty} g(x,y) \exp\left[-2\pi i\left(\frac{xu}{\lambda f_L} + \frac{yv}{\lambda f_L}\right)\right] dx\, dy$$

Figure A-2. Optical Spatial Fourier Transform Calculations 25X1

provides an approximate 60,000:1 first order of magnitude figure of merit for comparing the inherent potential of electro-optics technology to wholly electronic technology.

Phase-Conjugate Optics

Phase-conjugate optics includes the phenomena of nonlinear optical effects associated with the precise reversal of both the direction of propagation and the phase factor for each plane wave in a beam of light. For example, a conventional plane mirror (figure A-3a) changes the sign of the k-vector component normal to the mirror surface while leaving the tangential component unchanged. An incoming light ray can be redirected arbitrarily by suitably tilting the mirror.

On the other hand, the phase conjugator (figure A-3b) causes an inversion of the vector quantity, k, so that the incident ray exactly returns upon itself, independent of the orientation of the conjugator. A simple extension of figure A-3 indicates that an incident diverging beam would be conjugated to become a converging beam, and an incident converging beam would be conjugated to become a diverging beam. 25X1 25X1

In figure A-4a, a light ray is redirected by a phase-conjugate reflector. In figure A-4b, a wedge has been placed into the beam slightly redirecting the beam on

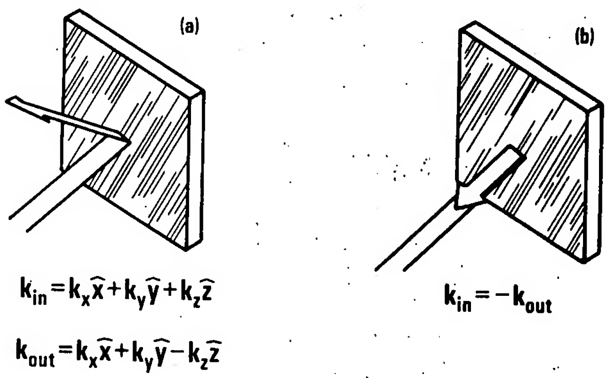

Figure A-3. Phase-Conjugate Optics
a. Mirror Reflector
b. Phase Conjugate Reflector

its way to the conjugator. Note that the conjugate beam returns to the same spot on the wedge and the return beam is subsequently deflected by the wedge to continue retracing the path of the incoming beam. The properties of the conjugate beam are not impaired by the interposition of a distorting medium (the wedge) as long as all the distorted light strikes the conjugator. The argument clearly extends to an array of randomly oriented wedges and thus to any phase distorter. This remarkable property indicates that, through optical-phase conjugation, a high-quality optical beam can be double passed through a poor-quality optical system with no loss in beam quality.

In addition to the aberration-correcting properties, phase conjugators can be used for pointing and tracking. To visualize pointing applications, consider what would happen if one were looking into a phase-conjugating mirror. An observer would see his or her face in a conventional mirror but not in a phase conjugator. This is because any light emanating from a particular point on the face would be returned by the conjugator to the same point, thereby not entering the viewer's eye. The only light seen by the observer would be that which had struck the conjugator after emanation as a diffuse reflection of room light scattered from the cornea covering the pupil of either eye. If the observer increased the illumination of one eye (perhaps by using a flashlight), the entire conjugator would appear, to that eye only, to become relatively brighter. Obviously, the viewer's observations would be unaltered if an aberrating medium were placed between the viewer and the conjugator. Thus we have the essential feature of the pointing application. As figure A-5 shows, a small glint from a diffusely illuminated target can propagate through an inhomogeneous intervening medium (such as a turbulent atmosphere). The light that enters the optical aperture of the device can be amplified in a possibly distorting laser amplifier. If the amplified beam were then to impinge upon a conjugator, a "reflected" or conjugate beam would be generated to pass in the reverse direction through the amplifier and then through the intervening distorting medium, and finally, to strike the target. This use of phase conjugation is an alternative to the conventional adaptive optics techniques for aiming a powerful laser at a small target. A small auxiliary laser illuminates a broad area, and some of the scattered light is gathered in the optical system and amplified in the gain medium. The phase conjugator then returns the beam through the gain medium and onto the target. This scheme can greatly reduce the required aiming precision and can compensate for any static phase distortions to the amplifier system, optical system, or intervening atmosphere. Similar problems are encountered in laser-fusion research and in other applications.

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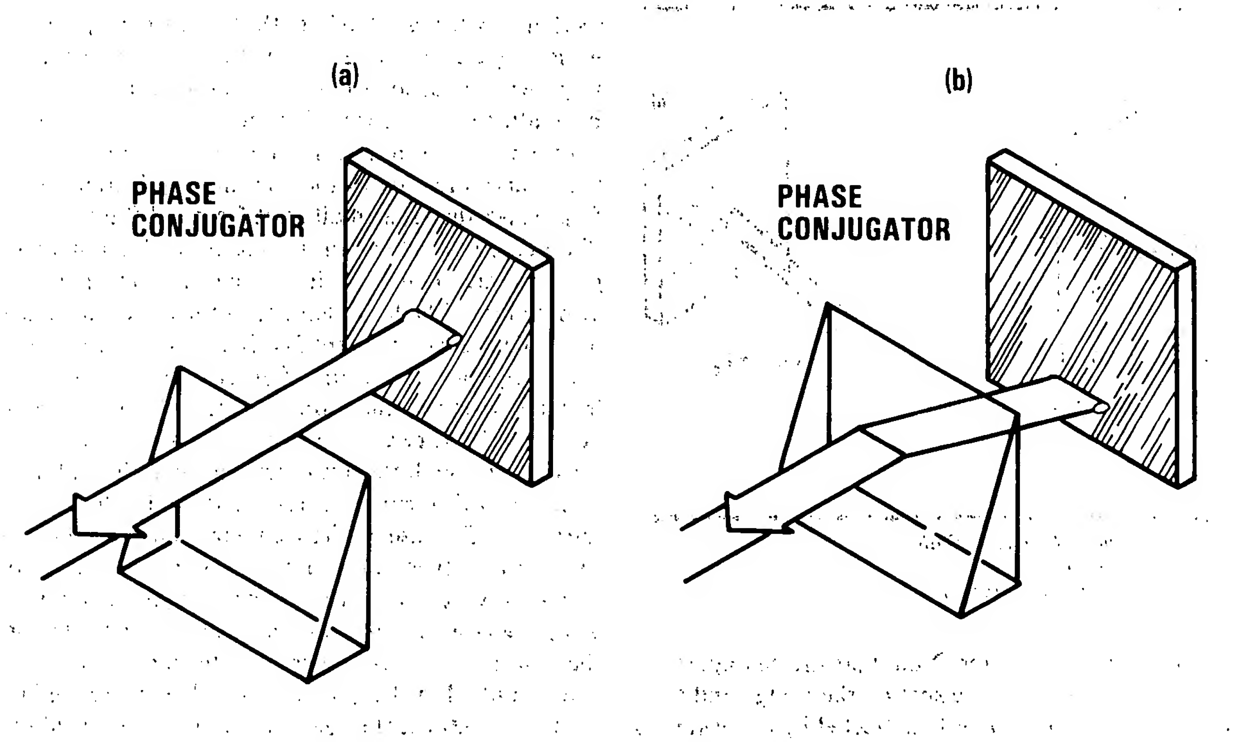

Figure A-4. Conjugate Beam Propagation Through an Inhomogenous Medium

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Photodetectors

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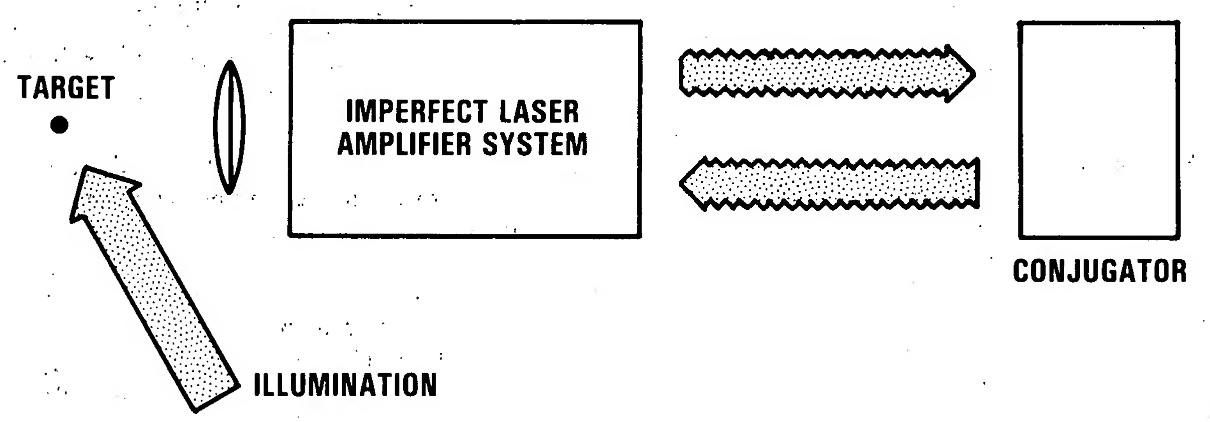

Figure A-5. Pointing and Tracking Application of Phase-Conjugate Optics [redacted] 25X1

Currently, the most common semiconductor UV detectors are surface-barrier metal-semiconductor structures made by the vacuum or chemical vapor deposition of extremely thin metal films on the surface of such semiconductors as Si, GaAs, GaP, or ZnS. In 1981 the Soviets improved the traditional formula by covering gallium selenide (GaSe) with a thin layer of indium and tin oxide (ITO) instead of a simple metal. ITO is transparent to visible and UV light, yet it conducts electricity and acts as a metal. This is an improvement over the standard materials used because the ITO is "brighter" than the metals and the GaSe itself possesses some superior material characteristics. The net result is a greater quantum efficiency in the near UV. The quantum efficiency is reported to be as high as 0.9 electrons/photon at 365 nm wavelength. [redacted]

In 1983 some other research was published on UV photodetectors using iron (Fe) doped indium phosphide (InP) on sapphire prepared through liquid-phase epitaxy (LPE). The material is described as being a "highly effective UV detector." Also, recent reports on LPE-prepared gallium aluminum arsenide (GaAlAs), indicate a quantum efficiency of 0.5 to 0.6 in the UV range. [redacted]

Early Soviet work on actual devices was reported in a patent for a UV photoresistor based on cadmium thiogallate ($CdGaS_4$). The devices that use $CdGaS_4$ detectors are the DUF-1 dosimeter and the TSUF-1 ratemeter. Both devices seem to be intended for gross measurements. [redacted] 25X1

The Soviets have had new ideas and invented novel materials, but these efforts have not resulted in militarily significant devices. This may, however, change in the future. A recent Soviet article described the Soviets' development of microchannel plates for UV use. These plates could be used in very sensitive imaging devices. [redacted] 25X1

Visible and Near Infrared. Based on analysis of Soviet work over the past decade in visible and IR detector materials and detection techniques, it is obvious that a large-scale research and development program has been under way. Extensive work has been done on detectors for the visible region to the near-IR region of the electromagnetic spectrum; this work has included photocathodes for television camera tubes and image intensifier tubes, as well as solid-state detector arrays. [redacted]

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The most common photocathode material for Soviet vidicons is antimony trisulfide (Sb_2S_3), but others, lead oxide (PbO_2) in the LI442 and silicon (Si) in the LI446, have been reported. For photocathodes in devices such as orthicons, isocons, image dissectors, and image intensifiers, the Soviets use mainly S-10 and S-20 photoemissive materials on the focal plane. Thousands of image converter tubes employing S-1 photocathodes have been produced and, since World War II, have been used extensively in night sights for ground forces. These sights require active illumination from IR searchlights and are currently being phased out in favor of passive image intensifier sights. The research and development of second- and probably third-generation image intensifiers using fiber-optic faceplates, microchannel electron multipliers, and advanced photocathodes, such as gallium arsenide (GaAs) and galium aluminum arsenide (GaAlAs), are currently under way. No second- or third-generation image intensifiers are known to have been produced for military applications. Descriptions of Soviet streak cameras contain information on some second-generation devices. [redacted]

[redacted]

Currently, the Soviets are advertising for sale on the world market a silicon photodiode array, the KDM-512. This array consists of 512 photodiodes, 0.03 x 0.03 mm in size, arranged in a 16 x 32 matrix. In addition, a linear silicon photodiode array, the K1200TIL-2, has been reported. This device consists of 2,048 light-sensitive cells and two CCD shift registers, one on each side containing 1,032 elements. The pitch of the diodes is 12 μm and the height is 10 μm. [redacted]

The most recent reports on Soviet CCD arrays reveal continued technological development and production capability. Linear arrays of 1,024-element photosensitive CCDs are serially produced and have the type number K1200TsL-1. These linear arrays have a pitch and height of 14 μm and are probably the ones used in the MSU-E multispectral scanner on board the Meteor-Priroda satellite. Two photosensitive CCD matrix arrays have been reported in type series, the K1200TsM-1 and the K1200TsM-2. The M-1 contains 288 (vertical) by 232 (horizontal) elements with upper (input) and lower (output) shift registers. The size of the light-sensitive cells is 24 x 24 μm. The M-2 contains 580 (vertical) by 360 (horizontal) elements with one upper (input) and two lower (output) shift registers. In addition, a CCD array, type KB1201TsP, has been reported to be used in the time-delay and integration mode, but no other information is available. In addition to the CCD imaging arrays mentioned above, the Soviets are producing a CCD array for the television camera that will be carried on the Venus/Halley's Comet probe. This array is reported to contain 512 x 576 elements of size 18 x 24 μm. The CCD array is designed to operate in the frame transfer mode where half of the array is used for storage or in a complete staring mode with image blanking during readout. As far as we know, all of the photosensitive CCD arrays described above are on silicon with overlapping polysilicon electrodes and a three-phase voltage clock for readout. [redacted]

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Mid Infrared. [redacted] 25X1

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The production of lead salt detectors by the Soviets is a mature technology. As early as 1971, a photoconductive 10-element PbSe array was used in an airborne infrared imaging system. A more recent report describes an IR imaging system flown on MI-2 Hoplite and MI-8 Hip helicopters and AN-2 Colt and

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Far Infrared. For far-IR detection the Poles and the Soviets have extensively researched HgCdTe photoconductors and photodiodes. Gold-doped germanium (Ge:Au) has been reported for airborne imaging systems as well. Pyroelectric detectors for laser detection and diagnosis have been produced using several materials such as triglycine sulfate (TGS), lithium niobate ($LiNbO_3$), barium titanate ($BaTiO_3$), and others. There is a continuing research and development program for hybrid IR/CCD detector arrays using HgCdTe/Si and $LiNbO_3$/Si and monolithic CCD structures in infrared detector materials such as HgCdTe.

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[redacted]

The only known application of HgCdTe detectors in an operational infrared imaging system is in the far-IR channel of either the Vulkan or Teplo-4 airborne line scan system announced by the Soviets in 1979. The article describing the systems stated that, for detection in the 8- to 13-μm bands, Ge:Au and HgCdTe are used. It seems likely that Ge:Au is used in one and HgCdTe in the other. It was also stated that the characteristics of both systems are similar, but only data were given for the Vulkan. The specifications that were given showed an IFOV of 8 arc minutes and an MRΔT of 0.25 C. Incidently, it was reported that InSb was used for detection in the 3- to 5-μm band for both systems. [redacted]

A great deal of research has been under way in the Soviet Union for several years on pyroelectric materials for IR detectors, and, recently, linear and matrix arrays of pyroelectric detectors have been reported. The linear arrays had 12 to 100 elements. The dimensions of the individual sensitive elements vary from 30 x 30 μm to 0.5 x 0.5 μm. The most common materials reported for Soviet linear pyroelectric detector arrays are TGS, $LiNbO_3$, and $BaTiO_3$. The matrix arrays reported so far are rather coarse devices with 25 elements (5 x 5) and 100 elements (10 x 10). The first matrix pyroelectric detectors were reported in 1975, and their stated purpose was for the investigation of the spatial-energy and time characteristics of lasers. The significance of pyroelectric detector development is the fact that these detectors operate at ambient temperature and have a flat wavelength response throughout the entire infrared region. The detectivity of pyroelectric detectors is normally 2 orders of magnitude less than BLIP semiconductor photondetectors, but, in applications where the signal-to-noise ratio is not a problem, their broad spectral response and uncooled operation make them desirable. [redacted]

[redacted]

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[redacted]

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Several institutes in the Soviet Union have reported developments in monolithic CCD IR detector arrays. The work describes some of the methods of producing the oxide layer between the semiconductor detector materials, for example, InSb and HgCdTe for the MOS structures. References were made to applications as sensitive detectors of infrared radiation. The work at the Siberian Physico-Technical Institute *imeni* Kuznetsov of the Tomsk State University is closely paralleling the work at Texas Instruments, Incorporated, as evidenced by repeated reference at the Texas Instruments work. The MOS structures being developed at Tomsk use LPE grown $Hg_{1-x}Cd_xTe$ with x-values ranging from 0.2 to 0.37, thus covering the mid- and far-IR bands. No information is currently available on array sizes or configurations [redacted] 25X1

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Extreme Infrared. The region of the electromagnetic spectrum from 100 to 1000 μm is referred to here as the extreme IR, but in Soviet writings it is usually 25X1

called the submillimeter range. Some innovative work on imaging in this range has been reported, but no military applications are currently evident. [redacted]

The Soviets have been working on superconducting bolometers based on double films of silver plus tin (Ag + Sn). The operation of the bolometer at liquid HeI and HeII temperatures was investigated. In HeI a decrease in sensitivity with frequency was observed, but in HeII the frequency characteristics of the bolometer remained uniform over the frequency range from 1.6 Hz to 30 MHz. For the latter, the sensitivity was reported as $D^* = 10^8 \mathrm{cmHz}^{1/2}\ \mathrm{W}^{-1}$ with a time constant of less than 5 ns. This work is significant because a group of Soviet authors have suggested improvements in their airborne thermal imaging systems by using high-speed bolometers because of their uniform wavelength response. [redacted]

An article published in 1978 described the construction of a three-channel "far" infrared detector using semiconductor photoresistors. The device operated at a temperature of 4.2K and used boron doped silicon (Si:B) for the band from 15 to 30 μm, boron doped germanium (Ge:B) for the band from 30 to 140 μm, and n-type gallium arsenide (n-GaAs) for the band from 100 to 450 μm. The three photoresistors were mounted in an integrating chamber at 4.2K, and the preamplifiers were in a cryostat at 77K. The noise equivalent power (NEP) for the three peak wavelength responses was reported as $5 \times 10^{-12}\ \mathrm{W\ Hz}^{-1/2}$ ($\lambda =$ 27 μm), $10^{-13}\ \mathrm{WHz}^{-1/2}$ ($\lambda =$ 100 μm), and $5 \times 10^{-14}\ \mathrm{WHz}^{-1/2}$ ($\lambda =$ 285 μm) with a time constant of 5 μs. The development of this three-channel detector is significant because it indicates the potential application as a broadband radiometer for operation in the extreme IR. The authors of the 1978 article stated that this detector was being used in a device for plasma diagnostics [redacted]

Technical Impact of Electro-Optics on Military Operations

There is no comprehensive, concise assessment available of the total potential impact of EO technology on military weapon systems. Based on a few known applications, however, some facts are evident. The force-multiplying impact of this technology has been studied over a period of years. The performance, size, weight, cost, and reliability of an EO signal processor for use in radars has been estimated and compared with those of an electronic digital signal processor. The following paragraphs will address these topics in more detail. [redacted]

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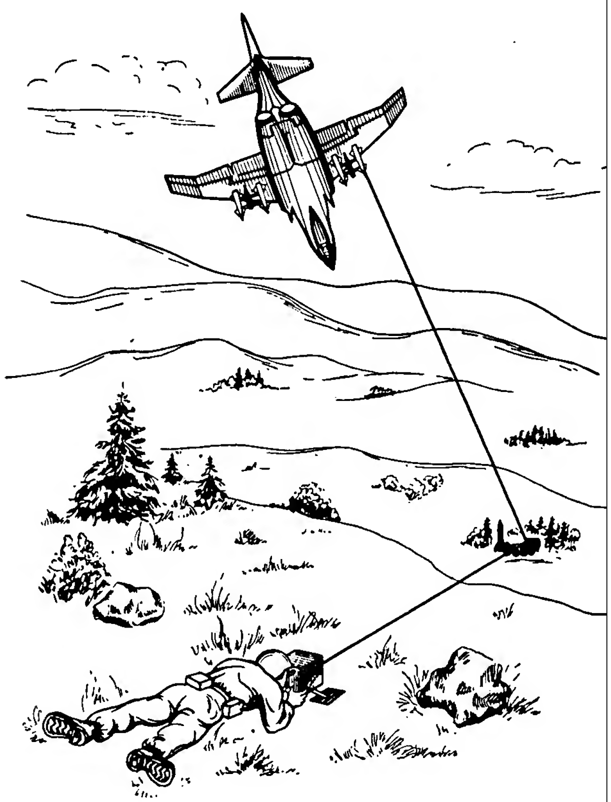

Figure A-6. Air-to-Ground Operations—
Electro-Optic Designator (Soviet Illustration

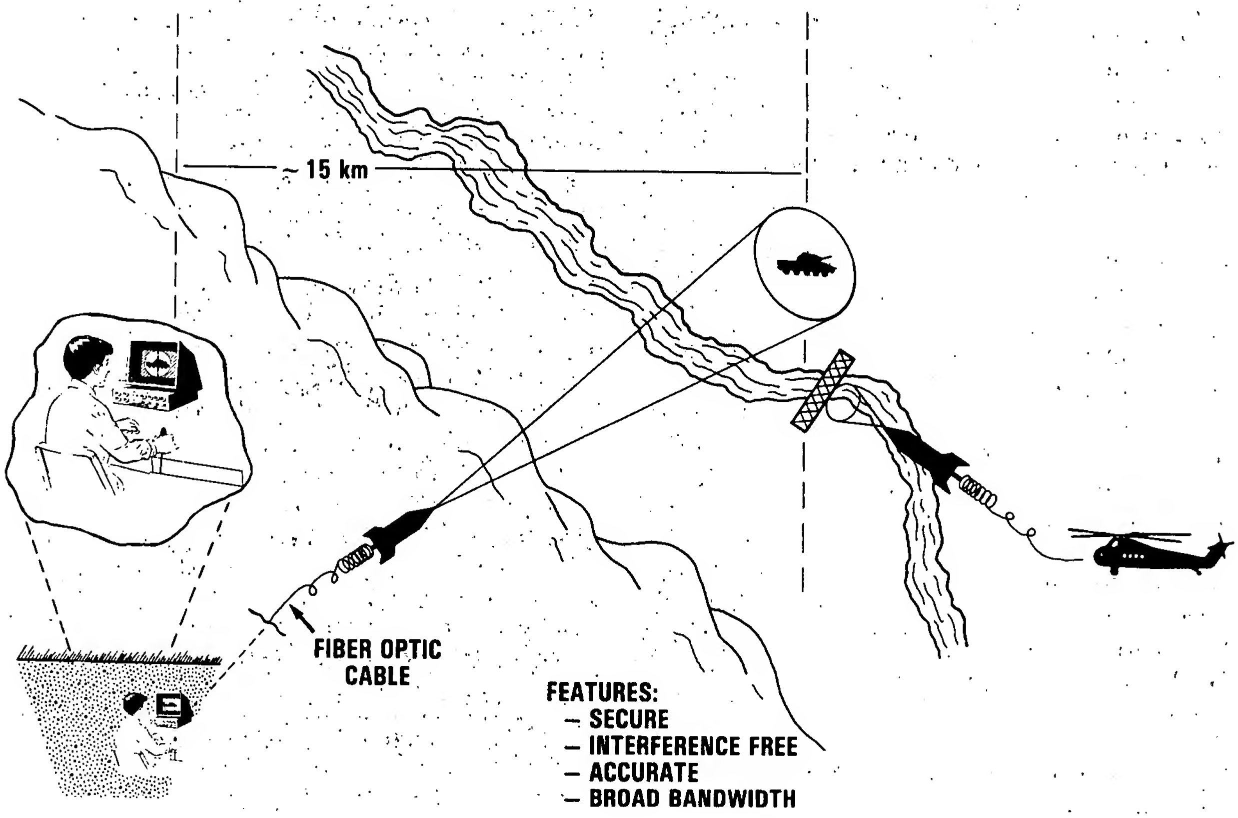

Figure A-7. Fiber-Optic Guided Antitank Missiles [redacted]

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Radar Signal Processing

Synthetic Aperture Radar (SAR) has important military value for use in surveillance, command and control, and reconnaissance systems. High-resolution (3 meter), real-time SAR data have recently become an available resource to the combat commander. The employment of real-time SAR as a sensor and target designator provides the battle commander with a highly effective force-multiplying capability that was

not previously available for air-ground combat operations. The Soviets have high-resolution SAR in the Foxbat D aircraft, but there is no evidence that they have developed a real-time SAR processing and display capability. Their electronic digital capability is probably not sufficient to support the high data throughput rates required of a real-time high-resolution SAR processor. [redacted]

[redacted]

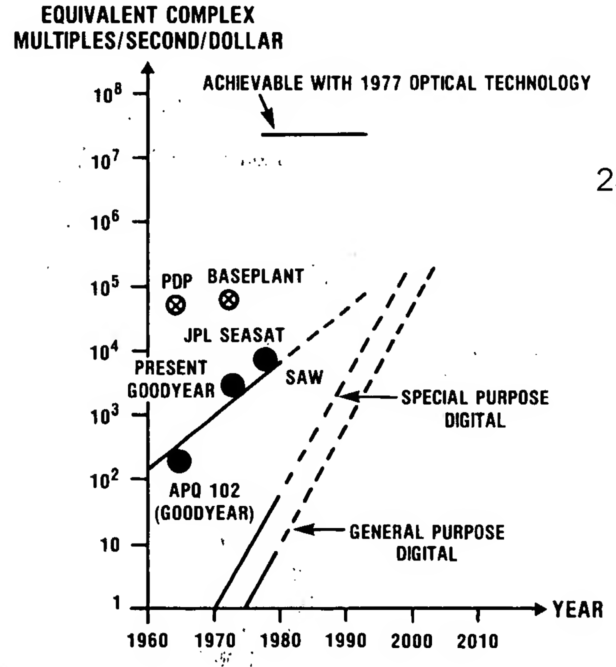

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Figure A-8. Electro-Optic versus Digital Radar Signal Processing [redacted]

25X1

Figure A-8 shows the performance impact for EO radar signal processors designed and deployed in specific US radars such as SEASAT. The figure clearly indicates that, for the six high-performance radars shown, the digital technology in the early 1970s was not adequate to support the radar processing requirement without undue cost. The ordinate in figure A-8, which is based upon empirical data, provides a figure of merit, "multiples/seconds/dollar," sufficient to compare SAW, EO, and digital technologies. By about 1990 digital technology will probably approach a "size barrier"—0.5 μm chip VHISC—limiting it to about 10^{10} operations per second. The cost incurred to exceed this performance will be excessive and will cause the digital curve to flatten out starting in the early 1990s. Figure A-9 shows two curves based on empirical data that illustrate the relative economic impact of EO versus electronic digital technology for various TB products. These data indicate that, for large TB values, EO radar signal processors are the most cost effective. One can easily visualize the technical performance and economic impacts of EO technology versus digital for radar signal processing applications. Radar signal processing requirements are considered to be the most stringent to meet. Hence, other military applications of EO technology will show a similar trend indicating favorable results. EO technology is also necessary to accomplish some functions that cannot be performed by other known or envisioned methods [redacted]

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[redacted]

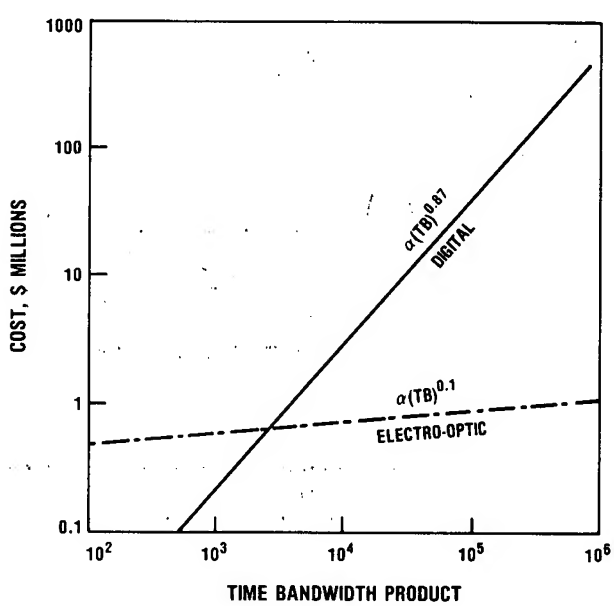

Figure A-9. Economic Impact of Electro-Optics versus Digital Radar Signal Processing [redacted]

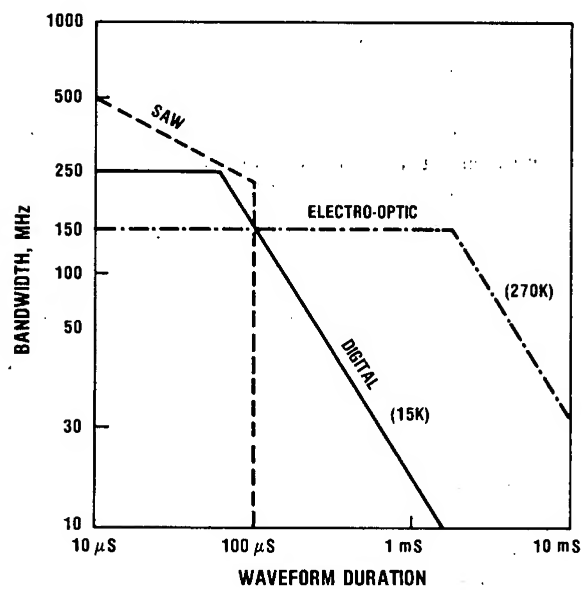

Figure A-10. Technology Map of Time-Bandwidth (TB) Data [redacted]

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[redacted]

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Electro-Optics Size, Performance, Cost, and Reliability Impacts

The preceding paragraphs have suggested that EO technology offers substantial performance advantages in specific applications. Engineers estimate that, in addition, the space (volume) required for an EO system is less than one-tenth that required for a digital system to accomplish an equivalent function. In many applications one to three orders of magnitude improvements can reasonably be expected. Also, based upon preliminary data from US programs, the development costs are believed to be about one-tenth that required for digital systems, and that reliability is enhanced one to two orders of magnitude. In addition, weight and overall operating power requirements are reduced substantially, and in many cases two to three orders of magnitude gain may be realized. The development of improved optical materials for SLM, photodetectors, and integrated EO systems is expected to further accentuate these favorable trends. It appears, therefore, that EO technology has all the important systems factors going in the right direction at the same time. The use of this technology in conjunction with microelectronics in future weapon systems will provide a corresponding payoff, with a related possible increase in reserve space for additional payload, fuel, propulsion, and command and control subsystems. A substantial gain in pointing and tracking technology may also be realizable using conjugate optics [redacted] 25X1

Fiber Optics Resistance to Nuclear Radiation and Electromagnetic Pulse

Although the Soviets have indicated their familiarity with nuclear radiation effects on fiber-optic cable transmissivity they have not published very much in the open literature that includes specific test results. In any event, the effects of nuclear radiation are highly dependent upon the fiber-optic cable material and dopants used. Figure A-11 provides a general representation of the transient effects to be anticipated. During a nuclear burst, one can expect a strong light pulse that rapidly attenuates to a minimum transmission level and then slowly recovers to near the initial level. The time constant can vary from a few milliseconds to as long as one hour. However, the material and dopants can be selected to give predictable responses suitable to specific application requirements. The inherent resistance of fiber-optic cables makes it easier to design systems that are nuclear hardened [redacted]

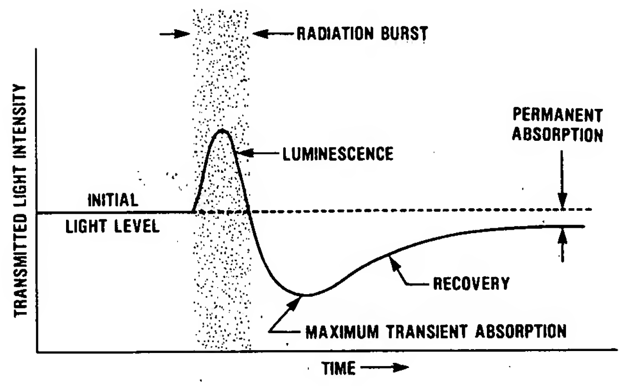

Figure A-11. Optical Fiber Cable Transmittivity Attenuation in a Nuclear Radiation Environment [redacted]

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[redacted]

Annex B

Parameter Tables

Table B-1
Soviet Low-Energy Lasers

Type of Instrument	Wavelength (µm)	Mode	Pulse Width (µ sec)	Repetition Rate (kHz)	Emissive Power		Diameter of Beam (*mm*)	Divergence of Beam (*minutes*)	Lifetime (*hr*)	Size Dimensions (*mm*)
					Multiple Mode (*mw*)	Single Mode (*mw*)				
a. Gas lasers										
OKG-11	0.6328	Continuous	NA	NA	2	1	1.5	10	500	550x400x300
OKG-12	0.6328	Continuous	NA	NA	10		3x10	10x40	500	1160x120
OKG-12-1	0.6328	Continuous	NA	NA	10		4	10	500	1160x120
OKG-13	0.6328	Continuous	NA	NA	0.4	0.2	1.3	7	500	262x46
OKG-15	10.6	Continuous	NA	NA	10		3	40	500	640x195x180
OKG-16	0.6328	Continuous	NA	NA	NA	0.1	1	7	500	180x46
LG-36	0.6328	Continuous	NA	NA	40	20	4	5	750	153x290x300
LG-36A	0.6328	Continuous	NA	NA	80	40	5	5	500	188x290x300
LG-38	0.6328	Continuous	NA	NA	NA	50	2.2	1.8	750	2000x320x290
LG-55	0.6328	Continuous	NA	NA	2	1	2	5	500	360x70x60
LG-56	0.6328	Continuous	NA	NA	2mw			10	500	350x58x58
LG-65	1.15	Continuous	NA	NA	20mw		6	15	300	1110x150x120
LG-75	0.6328	Continuous	NA	NA	25mw		5	10	500	1080x109x112
LG-75A	3.39	Continuous	NA	NA	20mw		6	10	500	1080x109x112
LG-126	0.6328; 1.15; 3.39	Continuous	NA	NA	10mw on each wave length			10	750	1150x126x146
LG-169	0.6328	Continuous	NA	NA	20mw		4	15	300	700x130x115
LG-106	0.4880	Continuous	NA	NA	1w		3.5	4		1075x290x280
LG-109	0.4880	Continuous	NA	NA	1w		3.5	6		670x320x130
LG-187	10.6	Continuous	NA	NA	15w		6	30	300	1600x300x300
LGI-17	1.118; 1.15; 1.206	Pulse	0.8	0.2-5	50w;40w; 10w		15	20		150x170x1070
LGI-26	2.026; 3.43; 3.51	Pulse	0.15-0.5	0.2-5	100w;50w;20w		15	10	300	150x170x1070
LGI-37	0.526; 0.5353; 0.5397; 0.5955	Pulse	0.3-0.35	0.1-0.7	2kw total		5	6		1500x400x345
LG-149[a]	0.6329914	Continuous	NA	NA	NA	0.5		3		820x350x170
LG-159[b]	0.6328	Continuous	NA	NA	NA	10	5	2		1900x230x190

Footnotes appear at end of table.

Table B-1 (Continued)

Type of Laser	Energy Pulse	Pulse Power	Pulse Width	Beam Divergence	Beam Diameter	Pulse Repetition Rate	Type of Q Switcher	Pumping Mode	Year	Operating Mode
b. Solid-state lasers										
Ruby										
GOR-0.2	0.2J	—mW	0.12 msec	11 mrad		0.03 Hz				Free lasing
GOR-100	100		1 msec	11		0.005				Free lasing
GOR-300	300		6 msec	9		0.005 (1 pulse/ 5 min)			1968	Free lasing
OGM-20	0.4	20		0.5		1	E-O			Multimode
			(20 nsec)	(2)						Giant pulse
OGM-40	0.6-0.8	40	(15-20 nsec)	0.3		1/60	Modulated	Q Mode	1974	Giant pluse
GOM-1	0.5	30-50	(10-15 nsec)			1/20	O-M			Giant pulse
			(10-15 nsec)							Single mode
FIAN	2.5	250	10 nsec	2		1/3	E-O			
GD-312	400 mJ		20 nsec			6.24			1964-65	
NS-64	400 mJ					6			1974	
IT-84	600 mJ					1			1969	
	1J		25 nsec			1				
Neodymium: glass										
GOS-301	300J	0.380 mW	0.8 msec	6 mrad	—mm	1/300				Free lasing
GOS-1000-1	1000	1	1	6		1/480				Free lasing
Neodymium: aluminum yttrium garnet										
LT-1		(1-3)x10 10^{-6}		6	3.4					Continuous multimode
LT1-3	0.02	3	10	6	12.5			Pulsed		
LT1-5	0.05	5	10	6	25,50,100			Pulsed		
Second harmonic (0.53 μm)										
Type of laser			Lasing Med	Pulse Power		Pulse Repetiton Rate	Pulse Width	Type of Doubler		Conversion Efficiency
LTIPCh-3 -6			YAG	0.5-1.0 mW		12.5;25;500; 100 Hz	10 nsec	Lithium niobate		
LTIPCh-1			GLASS	10 1000		0.1 1/300	15 20			10%

[a] Single-frequency, highly stable laser; frequency instability after eight-hour operation no more than 5.10^{-9}; frequency regeneration 4.10^{-8}; the instrument provides for frequency retuning of ±250 MHz.

[b] Single-frequency, stable gas laser with increased emissive power; frequency instability after eight-hour operation no more than 1.10^{-8}

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Table B-2
Soviet CO_2 Closed-Cycle Electric Discharge Lasers

a. CW Mode						
Designator	LT-2	TL-10	ISET	23E	(unknown)	TL-5
Average power (kw)	18	10	10	10	7.5	7
Efficiency						
System (%)	9	8	5	7		
Electro-optic (%)		15		15	12.5	7
Gas						
Constituents	CO_2:N_2:He	CO_2:N_2:air	CO_2:N_2:He: Xe:CO	CO_2:(N_2:air)	CO_2:N_2:He	CO_2:air
Ratio	1:12:12	1:9:10	1:31:15:0.8:1	1:19	3:45:51	
Pressure (torr)	450	25	50	25	50	30
Renewal (%)		0.4	Catalytic regenerator	0.5	0.5 to 1.0	0.5 to 1.0
Flow velocity (m/sec)	90	90	90	80	117	120
Compressor/fan		Two AI-24 aviation compressors	Centrifugal fan	Two axial-flow compressors	Two 3-stage axials	Two AI-24 aviation compressors
Discharge						
Volume (l)	3.3		20		13.2	
Width (cm)	5	35	20	40	27	
Height (cm)	5 to 6 trapezoidal	6	10	6	5.3 to 5.7 trapezoidal	3.8
Length (cm)	120		100		89	130
Specific input (J/g)	250	240	300			150
Type	125 kv E-beam 40 μA/cm²	DC glow preionization	120 kV E-beam 70 μA/cm²	Self-sustained	Electric discharge preionized	
Optics	Unstable, M=1.18	4-pass unstable confocal	plane telescopic, M=1.3	4-pass unstable confocal	3-pass unstable telescopic, M=1.63	Unstable, M=1.15
Window	KCl annular beam 5 x 3.6 cm	KCl rectangular beam 2.5 x 4.5 cm	NaCl	KCl annular beam 5.5 cm OD	NaCl	KCl annular beam 8 cm OD
Dimensions (m)		2.7x3x2.8		2.7x3.0x2.8		2.5x1.95x1.6
Facility	FIAEh	FIAEh NITsTLAN	FIAN SSSR	NITsTLAN	KAI IFAN BSSR	FIAEh NITsTLAN

Table B-2
Soviet CO_2 Closed-Cycle Electric Discharge Lasers (Continued)

Designator	TsIKLON	LT-1	IGLAN	MKTL-2	LANTAN	MKTL-1	LGN-702 (Kardamon)
Average power (kW)	6	5	3	2.5	2	1.2	1
Efficiency							
System (%)				10		9	
Electric-optic (%)	10					13	
Gas constituents	CO_2:N_2	CO_2:N_2:He	CO_2:N_2:He		CO_2:N_2	CO_2:N_2:He	C_2:N_2:He
Ratio (torr)	1:7	1:20:30	1:1:8		1:7	1:1:6	0.7:2:7
Pressure	35	50	30		40	30	8
Renewal (%)		0.3					
Flow velocity (m/sec)	220				70	4	
Compressor/fan	AI-20 aviation	Two 2DNV-1500 pumps	VN-2 pump		Axial blower		
Discharge	27	7.2	11		8.3	1.825	
Volume (l)	65	20	Two sets	127 tubes	16	64 tubes	
Width (cm)			39 tubes			0.55 cm ID	
Height (cm)	5.5	4	1 cm ID		5.5		
Length (cm)	76	90	180 tube		94	120	
Type	60 kHz DC capacitive discharge	Self-sustained	DC discharge	10kHz AC capacitive	10-50kHz electric discharge preionization	10 kHz AC capacitive	
Optics	12-pass plane/concave	3-pass unstable	Plane	Plane	3-pass	Plane	
Window		KCl annular beam 5cm OD	KCl		ZnSe	ZnSe	
Dimensions (m)		4.2x2.1x2.95	4.6x1.3x1.9	1.8x1.3x1.9	2.5x1.0x1.65	2x0.7x1.2	6.5x0.72x 1.26
Facility	IPMAN	FIAEh NITsTLAN	IPMAN	FIAEh NITsTLAN	IPMAN	FIAEh	IFAN BSSR

Table B-2 (Continued)

b. Pulsed Mode						
Designator	KOKhTA DYaTEL-2	(unknown)	SVERTChOK	LPD-1	LGIT-1	LANTAN
Average power (kW)	10	5	1.5	1	1	1
PRF (Hz)	750	100	600	500	300	200
Average pulse energy (J)	14	50	2.5	2	3.5	5
Pulse length (μs)			4	300	15	10
Efficiency						
System (%)	5	6	5	5	5	
Electric-optic (%)	10	15			10	10
Gas						
Constituents	CO_2:N_2:He	CO_2:N_2:He	CO_2:N_2:He	CO_2:N_2:He	CO_2:N_2:He	CO_2:N_2:He
Ratio	1:1:5	1:6:3	2:1:5	10:45:45	1:5:5	1:3.3:10
Pressure (atm)	0.75	1	0.6	0.16	0.22	0.1
Renewal (%)	0.1 m^3/hr	1.5	Catalytic converter	Catalytic converter		
Flow velocity (m/sec)	100	11	60			70
Compressor/fan	Three axial fans		Axial	Two 2DVN-1500 pumps		Axial blower
Discharge						
Volume (l)	0.8	2	0.28	0.8	0.9	8.3
Width (cm)	4	6.5	2.8	4		16
Height (cm)	2.5	4.5	2	4		5.5
Length (cm)	40	70	50	50		94
Type	UV preionized	150 keV E-beam 60 mA/cm^2	UV arc preionized	UV preionized and plasma cathode	Electric discharge preionized	10 to 50 kHz electric discharge pre ionized
Optics	Unstable	3-pass unstable m=1.8		Plane	Stable	3-pass
Window	ZnSe			KCl		ZnSe
Dimensions (m)	2.5x1.5x1.75		1.0x1.6x2.0		2.16x1.58x0.82	2.5x1.0x1.65
Facility	FIAEh	VNIIEhFA	FIAEh	FIAEh	NIKIMT	IPMAN

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Table B-3
Soviet EO Light Modulators

	Soviet Device Designation	Functional Description	Material	Special Region, µm
Electro-optical shutters and high-frequency modulators	OMG-48	Shutter for small solid-state lasers	$LiNbO_3$	1.06
	OMG-9	Shutter for protecting photomultiplier tube (PMT) against background	DKDP	0.4 to 1.5
	OMG-41 (PD-94)	Amplitude modulator for optical range-finders	DKDP	0.63 0.53
	OMG-35	Amplitude modulator for optical range-finders	ZnSe	0.63
	OMG-22 (PD-29)	Phase modulator for heterodyne systems	$LiNbO_3$	1.06
	OMG-3	Amplitude modulator for optical information transmission lines	GaAs	10.6
	OMG-30	Phase modulator for heterodyne systems	CdTe	10.6 1.06
Electro-optical microwave frequency modulators	OMG-14	Amplitude modulator for optical information transmission lines	ZnSe	0.63
	OMG-28 (PD-47-48)	Amplitude modulator for optical information transmission lines	ZnSe	0.63
	OMG-34	Amplitude modulator for optical profilometers	$LiNbO_3$	0.63 1.06
	OMG-42 (CD-339)	Amplitude modulator for optical rangefinders	$LiNbO_3$	0.63 1.06
	MG-31	Amplitude modulator for optical rangefinders	CdTe	10.6 1.06
Acousto-optical shutters, modulators, deflectors	OMG-46	Shutter for solid-state frequency laser	Fused silica	1.06
	OMG-29	Modulator for radiation frequency conversion in heterodyne systems	STF3 glass	0.63
	OMG-17	Modulator for radiation frequency conversion in heterodyne systems	Germanium	10.6
	OMG-21	Amplitude modulator	Germanium	10.6
	OMG-44	Deflector	Lead molybdate	0.63
	OMG-45	Deflector	Paratellurite	0.63
Electro to optical low to frequency and spatial modulators	OMG-12	Amplitude modulator for scientific re to search purposes	PMN	0.4 to 0.7
	OMG-2 (PD-41)	Amplitude modulator for information display systems	PMN (transverse effect)	0.4 to 0.7
	OMG-38	Wide to aperture amplitude modulator for information display systems	PMN (longitudinal effect)	0.4 to 0.7
	OMG-40	Matrix spatial modulator for information processing systems	PMN	0.4 to 0.7
	OMG-39	Spatial modulator for light to controlled information processing systems	Bismuth silicate	Write 0.3 to 0.68, read 0.63 to 5.0

25X1

Table B-4
Parameters of Photodetectors

Detector Material	Operating Mode	Temperature (K)	Spectral Range (μm)	Peak Wavelength (μm)	Detectivity (cm $Hz^{1/2}$ W^{-1})	Time Constant (μs)
Si	PC	295	0.4-1.1	0.8-0.9	(0.5-1)x10^{12}	5
Si	PV	295	0.4-1.1	0.8-0.9	(2-10)x10^{12}	0.5
PbS	PC	295	1-3	2.5	(0.8-1.5)x10^{11}	300
PbS	PC	195	1-3.5	2.7	(4-7)x10^{11}	5,000
PbS	PC	77	1-4	3.1	2x10^{11}	3,000
Ge	PV	295	0.4-1.5	1.5	5x10^{11}	0.1
PbSe	PC	295	1-4.5	3.4	2x10^{11}	2
PbSe	PC	195	1-5.1	4.1	(2-5)x10^{10}	30
PbSe	PC	77	1-6.5	4.8	(3-5)x10^{10}	40
InSb	PC	77	1-5.4	5.3	(0.8-1)x10^{11}	5
InSb	PV	77	1-5.3	5.1	(1-11.2)x10^{11}	1
InAs	PV	77	1-3.5	3.1	(4-7)x10^{11}	0.5
Ge:Au	PC	60	2-9	5	(1-2)x10^{10}	0.1
Ge:Hg	PC	27	2-14	10.5	(2-5)x10^{10}	0.2
Ge:Cd	PC	4.2	2-23	16	(2-4)x10^{10}	0.1
Ge:Zn	PC	4.2	2-38	36	(2.5-5)x10^{10}	0.02
Ge:B	PC	4.2	30-140	100	3x10^{12}	20
HgCdTe	PC	77	3-6	5	(1-5)x10^{10}	0.01
HgCdTe	PV	77	8-13	10.6	(0.5-2)x10^{10}	0.01
PbSnTe	PV	77	8-13	10.6	2x10^{10}	0.05
Si:In	PC	4.2	2-7.5	6	1x10^{10}	0.01
Si:Ga	PC	18	4-17	15	2x10^{10}	
SiSe	PC	4.2	12-23	20	(1-2)x10^{10}	0.5
Si:B	PC	4.2	15-30	25	6x10^{10}	4
Ag+Sn	Bolometer	2	1-1,000		9x10^{7}	0.005
TGS	Pyroelectric	295	1-1,000		(0.2-2)x10^{9}	30 to 1,000
$LiNbO_3$	Pyroelectric	295	1-1,000		(0.05-1)x10^{8}	1,000
$BaSr(NbO_3)$	Pyroelectric	295	1-1,000		(0.1-2)x10^{8}	30
$LiTaO_3$	Pyroelectric	295	1-1,000		6x10^{7}	50
$BaTiO_3$	Pyroelectric	295	1-1,000		(2-5)x10^{7}	50,000

25X1

Table B-5
Materials Suitable for
Electro-Optic Devices (U)

Crystal Structure	Crystal Name	Spectral Transmission, Interval (μm)
Tetragonal	Potassium dihydrogen phosphate KH_2PO_4 (KDP)	0.2 to 1.5
	Deuterated potassium dihydrogen phosphate KD_2PO_4 (DKDP)	0.2 to 1.5
Trigonal	Lithium niobate ($LiNbO_3$)	0.35 to 5
	Lithium tantalate ($LiTaO_3$)	0.35 to 5
Cubic	Zinc selenide (ZnSe)	0.5 to 20
	Zinc sulfide (ZnS)	0.35 to 20
	Lead magnesium niobate $Pb_3MgNb_2O_3$ (PMN)	0.35 to 5
	Gallium arsenide (GaAs)	1.0 to 20
	Cadmium telluride (CdTe)	0.8 to 20
	Bismuth silicon oxide $Bi_{12}SiO_{20}$ (BSO)	0.3 to 5.0

25X1

Table B-6
Soviet Laser Communication Systems

Date	Laser	Capacity	Range (*km*)	Location	Remarks
a. Gas					
1965	He-Ne	Single-channel TV	Lab demonstration	Unknown	Kerr cell modulator, 5.5-MHz bandwidth
1965	He-Ne	Single-channel voice	5	Moscow University	
1968	He-Ne	24-channel voice	25	Yerevan	PPM [a] photomultiplier detector
1968	He-Ne	12-channel voice	Approx. 18	Moscow Krasnogorsk	
1969	Unknown	24-channel voice	Unknown	Kuybyshev	
1969	He-Ne	1 MHz	3	Klaypeda	
1969	He-Ne	1 MHz	5	Gorkiy	
1970	He-Ne	Single-channel voice	Several	Kirgiz	High-altitude mountainous experiment
1971	He-Ne	Single-channel TV	2	Tbilisi	
1971	Unknown	Unknown	5.2	Estonia (Tallin)	Test link for evaluation of various types of lasers
1971-1972	CO_2	Unknown	41	Yerevan	200-W CO_2 lasers
1971				Moscow Tula	
1972	Unknown	Voice and TV	83	Kirgiz	Standard gas lasers used over an 83-km straight path at an altitude of 2,000 m above sea level
1972	Unknown	Unknown	6	Tallin	Two links
1974	Unknown	40-channel TV	Unknown	Kiev University	
1975	CO_2	Voice?	Unknown	Field tests by army units	8 W out, LG-59 laser
1975	He-Ne	PCM [b] and/or computer-to-computer	1.2	Tallin	LG-36 and LG-56 lasers; photomultiplier detector
1980				L'vov	Polarization modulation
b. Semiconductor					
1968	GaAs	Unknown	Lab experiment	Moscow	Repeater amplifier (pulsed) experiments at 77K
1969	GaAs, GaPAs	96-channel voice	Less than 1	FIAN, Moscow	PCM at 77K
1970	GaAs	Single-channel voice	5	Commercial item	Hand-held transceiver (TO-2) PCM at room temperature
1970	GaAs	Single-channel voice	6	Commercial item	Tripod-mounted transceiver (MOLS-1) PCM at room temperature
1971	GaAs	Single-channel voice (?)	5	Voyeykova (near Leningrad)	PCM
1974			1.5	Moscow	PPU-1
1981		6.5 MHz		Moscow	LKS-2, PCM

[a] Pulse-position modulation.
[b] Pulse-code modulation.

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Table B-7
Thermal Imaging Systems (TIS)

Names of System	Min. Resolvable Temp. Difference (thresh sens) (°C)	Field of View (angular degrees)	Spatial Resolution (angular min)	Frame Period(s)	Lines Per Frame	Radiation Detector	Cooling Method	Display	Continuous Operations (h)	Spectral band (μm)
Rubin-1	0.05 (at 25)	20x10	7	60		InSb	Liq.N_2	ECP [a]		3 to 5
Rubin-2	0.1	20x15	8	60	150 (170 pxls/line)	InSb (FS-36LA)	Liq.N_2	ECP [a]	1.5	3 to 5
Rubin-3	0.1	20x20	6±1	40	240	InSb	Liq.N_2	ECP [a] and CRT		3 to 5
ATP-12M	0.1-0.3	11x15		5	250	InSb	Liq.N_2	CRT and photo	6	2.0 to 5.6
Yantar	0.2 (at 25)	5x4	5	0.04		InSb	Liq.N_2	CRT		3.5
Raduga	0.2	7.5x5	4x6	0.04	150 (50 pxls/line)	InSb (50-element)	Liq.N_2	CRT	2.5	2.0 to 6.0
Almaz	0.2 (at 30)	20x17.5	8	0.04	132 (140 pxls/line)	InSb (11-element)	Liq.N_2	CRT	3 to 5	
IK-10P	0.3	5x3.5	5	0.056	100	InSb	Liq.N_2	CRT		
IK-10T	<0.5	80	10	0.05						1.0 to 5.6
Stator	1.0	360	20		Variable	PbSe (SF4-1)	Uncooled	ECP [a]	NA [b]	1.8 to 4.8
Stator-1	1.0	360	23	(0.5 s/line)	Variable		Uncooled	ECP [a] and CRT	NA [b]	
Taiga	2.5 (at 20)	120	20	NA [b]	NA [b]	PbSe	Thermo-electric	ECP [a]	NA [b]	3.2 to 4.7
Airborne on LI-2										1.8 to 5.3
First channel	0.5	54	5	NA [b]	NA [b]	PbSe (10-element)	Compressed N_2	Photo		Subranges
Second channel	0.3		70			PbSe (1-element)				3.2 to 5.3 3.6 to 5.3 4.2 to 5.3

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Table B-7 (Continued)

Names of System	Min. Resolvable Temp. Difference (thresh sens) (°C)	Field of View (angular degrees)	Spatial Resolution (angular min)	Frame Period(s)	Lines Per Frame	Radiation Detector	Cooling Method	Display	Continuous Operations (h)	Spectral band (µm)
Vulkan										
First channel	0.5 (at 20)	80	7	NA	NA	InSb	Liq.N_2 (closed loop)	Photo and CRT		3 to 5
Second channel	0.25 (at 20)					GE:Au (HgCdTe)				8 to 13
TV-03	0.2	4.5x4.5	4	0.0625	100			CRT		
Filin	0.2	20x10	3.4	60-840	122 (244 pxls/line)	Bolometer	Uncooled	Photo	NA	0.7 to 40
TP-02 (Polish)	0.5	8.5x8.5	8.6	0.0625	100	InSb HgCdTe?		CRT		3.0 to 5.6
15-71-03 (Polish)	0.1	10x10	4.1	60	125 (150 pxls/line)	PbTe	Liq.N_2	CRT		1.1 to 5.7
HS-3B (Chinese)	10.2		9	NA	NA	Ge:Hg	Ne and Nz	Photo	8	8 to 14
Satellite systems										
Last-ochka-65	0.6	70	80	NA	NA	Bolometer				8 to 12
MSU-E		2.6	0.156	NA	NA	Si (CCD) (3-1024 element linear arrays)	Uncooled		NA	0.5 to 1.0 [c]
VS-1 and VS-2		7.5	0.4	NA	NA					
First channel						Si (CCD) (matrix array)	Uncooled	Compute processing	NA	0.4 to 1.1
Second channel						Insb (matrix array)	Uncooled?		and display	1.2 to 2.4
Third channel						InSb (linear array)				3.2 to 4.2
Fourth channel						HgCdTe (matrix array)				8 to 14

[a] Electrochemical paper.
[b] Not applicable.
[c] Not TIS but included here to indicate level of fielded capability.

Annex C

Glossary of Terms

Acousto-optics Technology that utilizes the effects of an acoustic wave in a material to affect light propagating in the material; also see Bragg cell.

Adaptive-optics Technique of changing in real-time, optic parameters of a system so as to compensate for certain undesirable effects (for example, atmospheric turbulence).

Aperture Size of the "opening" of a receiving element seen by the impinging electromagnetic wave.

Bragg cell Device based on the Bragg effect, in which an acoustic wave in a suitable crystalline material produces local refractive index changes, producing diffraction of a light beam traveling in the same medium and thereby causing an interaction between the signals represented by the light and acoustic waves.

Bulk acoustic wave Acoustic wave propagating in the volume of a medium (device) as opposed to surface wave propagation.

Coherent light Light of a single frequency (color) and constant phase, needed for most classes of signal processing, available from a laser.

Conjugator Device or system providing phase conjugation.

Convolver Device or system performing the mathematical equivalent of convolution or correlation; this entails the processes of multiplication of all points of a function with each and every other one (in one or more dimensions) and the summation of products.

Detectivity A figure of merit parameter of an optical detector; the reciprocal of noise equivalent power that related to the minimum detectable signal; denoted by D it is expressed in reciprocal watts; in addition, the specific detectivity D* is normalized to size and bandwidth (to the half power) and reciprocal power.

Diffraction efficiency The ratio of diffracted light to incident light in certain electro-optic devices.

Doppler frequency A frequency shift or signal superimposed upon a coherent wave by a moving object that emits or reflects the wave.

Electronic digital A term used in this report to denote conventional, nonoptical data or signal processing.

Electro-optic deflector One of a class of devices that employs the electro-optic effect to deflect (that is, modulate) an incident light beam.

Fiber optics A technology based on the use of optical fibers that are glass (or plastic) waveguides of light; distinguishes itself from conventional communication techniques through large bandwidth and resistance to interference.

Focal plane array An array of detectors operating in the focal plane (rather than image plane) of an optical system.

Four wave mixing or degenerate four wave mixing A phenomenon taking place in a nonlinear medium, in which two waves (pump beams) interfere to produce a periodic charge pattern that acts as a diffraction grating in such a way that a third, incident probe beam produces a fourth signal beam directly reflected upon the probe beam; the latter two beams have the desired characteristics for a phase conjugator.

Fringe pattern The spatial pattern formed by the interference of two waves (of light); for simple shapes (for example, pin holes or slits) of the contributing beams, regular patterns of light and dark "fringes" are observed.

Gain medium Laser medium, that is, the material which, when pumped in the laser sense, will amplify a light beam propagating through it by the mechanism of stimulated emission (laser action).

Geodesic lens A hemispherical dome-shaped device that refracts light to generate two nodes at opposing surfaces; see also Luneburg lens.

Glint Strong specular reflection from an object.

Grating A periodic optical structure that wavelength selectively diffracts an impinging plane wave.

Harmonic generation A nonlinear effect that produces from a signal another one of double or integer multiples of the original frequency; optically this occurs in certain crystals (for example, KDP) with the resultant light of shorter wavelength; since the original light beam is usually also present in the resultant as well as other undesired products, the conversion efficiency is always less than one.

Holographic memory	A medium in which input information is stored holographically, that is, in the form of a local refractive perturbation that produces a corresponding phase perturbation in a read-out beam; the memory can be of a permanent or volatile type, the latter usually being necessary for signal processing in real time.
Hybrid computer	In the context of this report a mixed system of both optical computing or signal processing elements and conventional digital electronics.
Image converter	A class of electron tubes or similar devices that convert an optical image into a stream of electrical signals for the purpose of transmission or processing.
Image enhancement	One of various techniques used to process an optical image so as to improve the ability of the human observer to extract information; examples are contrast enhancement, dynamic range compression, edge enhancement, deblurring.
Index of refraction	Characteristic of an optical material; the ratio of the speed of light in space to the speed of light in the material.
Infrared	See spectrum.
Ion implantation	A process of bombarding the surface of a material with ions that modifies the recipient material electrically (as used in semiconductor manufacture) or mechanically (as used in surface hardening).
Isotope separation	See laser photochemistry.
Laser	Originally the acronym for Light Amplification through Stimulated Emission of Radiation, now a class of devices producing highly coherent, collimated, monochromatic light.
Laser photochemistry	Technology of producing selectively desired chemical reactions based on the interaction of matter and light (photochemistry); with laser light as the activating energy, high selectivities are achievable; isotope separation is a prime application of these techniques.
LIDAR	From light radar; radar-like instrumentation using light (to include infrared) and some of the characteristics specific to light (for example, differential absorption).
Line scan imaging	A historical term applied to imaging (primarily in the infrared), produced by scanning the image with a small number of detectors in consecutive lines.

Multiplexing, spectral multiplexing	Techniques of superimposing multiple channels of information upon one transmission channel by the assignment of different spectral regions to each information stream; optical multiplexing, for example, could employ many signals each of a different carrier wavelength to simultaneously and without interference propagate over one optical fiber channel.
Multiples per second	Measure of throughput rate of digital system; elementary operations per second.
Nonlinear optics	Generally large area of optics and related technologies dealing with nonlinear effects, that is, those regimes where output signals cannot simply be described by a linear combination of inputs, that is, classical transmission, absorption, reflection, refraction; includes many important effects such as bistability, mixing, harmonic generation.
Optical bistability	Phenomenon of two distinct and stable optical states in one medium or device (for example, transmission/capacity or two states of polarization); examples are optical switches, liquid crystals, or optical digital memories.
Optically induced diffraction grating	An effect in certain materials (that is, photorefractive materials, liquid crystals, long chain polymers) where the interaction of two light waves produces electrically periodic structures that act as diffraction gratings; see also four wave mixing.
Opto-electronics	Device or technology that interfaces between optical and electrical signals (input usually optical).
Parametric mixing	Signal mixing process (mathematically multiplication in which new frequencies are produced) in which one of the two or more interacting signals affects the parameters of the energy storing medium; a process inherent in four wave mixing.
Phase conjugation	A process that produces the mathematical conjugate of a given signal (same amplitude and opposite phase); a major approach to propagating optical signals through distorting media.
Photoconductivity	Light-induced change in conductivity of a material.
Photodetector	Device that detects optical signals using one of numerous principles of operation, for example, photoconduction photovoltaics, pyroelectrics, photoemission.
Photodiode	A common photodetector.
Photovoltaics	Light-induced redistribution of charges in a material producing a voltage.

Photolithography	Technique of printing, for example, integrated circuit manufacture, using light and light-sensitive resists.
Polysilicon	Silicon material with multiple crystalline boundaries (as opposed to amorphous or monocrystalline material).
Pyroelectric	An effect in which infrared light (heat) causes an electric signal.
Q-switching	Refers to rapidly changing the Q-factor, that is, the resonance of an optical cavity; used to produce large pulsed outputs from solid-state lasers by permitting pump energy to build up followed by rapid and intense lasing action when the cavity becomes resonant.
Real time; near-real-time processing	Performance of a process that uses a stream of input data as it is produced, at the rate at which it is produced or faster; near-real-time processing is on balance at the rate of data generation but may include short-term storage and slower processing if input data are supplied in the form of discontinuous bursts.
Soliton	Stable, propagating, nondissipative wave structure observed in nonlinear systems.
Spatial frequency	Analogous to frequency defined for periodic time varying signals, spatial frequency is the rate of reoccurrence, in space, of a feature of a periodic intensity distribution in space; for example, sharp edges in an image have many high spatial frequency components.
Spectrum	The optical spectrum, as used in this report, comprises several (not rigorously defined) bands that include the ultraviolet, visible, and infrared, covering the wavelength regions from 10 nm to 1 mm.
Streak camera	A diagnostic, recording device for ultrafast processes; the high-speed event is "stopped" by the action for a flying spot scanning process in a suitable image converter tube.
Synthetic aperture radar	A type of radar that achieves angular resolution far better than given by the physical size (aperture) of its antenna, simulating a far larger antenna by sequentially moving its real antenna along a long baseline in space and coherently processing the returns as if they had arrived at one large (synthetic) antenna; a noteworthy advantage of this radar is its crossrange resolution being independent of range.
Terminal guidance	That final phase in the control of the flight of a missile nearest the target.

Thermoelectric effect A phenomenon found in some materials by which a temperature difference produces a voltage that can be sensed.

Term Within this report near-term is considered to span the next five years, mid-term about 15 years, and far-term the future beyond 15 years.

Waveguide A tubular medium within which an (electromagnetic) wave will propagate with little loss; at radio frequencies it usually takes the form of a metallic circular or rectangular cross section cylinder; at optical wavelengths specially designed glass fibers permit low loss propagation.

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Next 1 Page(s) In Document Denied